Investigation of Time Of Combustion in a Gas Engine Cylinder

E. H. Enander
W. S. Gaylor

1906

EXPERIMENTAL INVESTIGATION OF THE TIME OF COMBUSTION IN A GAS ENGINE CYLINDER

A THESIS

PRESENTED BY

EINAR H. ENANDER
WM. S. GAYLOR.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

JUNE 5 1906

Approved
G. F. Gebhardt
L. M. Raymond Dean of Eng. Studies

FLAME PROPOGATION IN A GAS ENGINE CYLINDER.

The time of combustion of an explosive mixture in a gas engine cylinder is a field in which very little practical work has been done. The "time of combustion", or what is commonly known as flame propogation, is that time which elapses between ignition and maximum pressure. It is a well known fact that the ignition of a charge in the gas engine must occur before "dead center" is reached so that the maximum pressure is exerted at this point. The ignition must be made earlier with reference to the crank position for an increase in speed and the usual method by which the proper point of ignition is determined is by means of the indicator. The type of card that usually gives the best results is well known and the ignition is shifted until the desired card can be obtained. If the time of combustion of the charge was known the point of ignition could be determined without the aid of an indicator.

The results that are quoted in text books on gas engines are drawn chiefly from two sources, namely: experiments by M. M. Mallard and Le Chatelier, also determinations made by Mr. Dugald Clerk. The data given by the above experimenters on the time of combustion were obtained with conditions differing from those actually existing in the cylinder. M.M.Mallard and

Le Chatelier made their first experiments along this line to disprove the results obtained by Bunsen. Bunsen had found by experiment that two volumes of hydrogen and one of oxygen burnt at a rate of 111.5 feet per second. He also found that the velocity of the flame in carbon monoxide was 3.28 feet per second. Mallard and Le Chatelier with the same mixture and conditions with which Bunsen made his experiments, determined that the velocity of combustion in hydrogen and oxygen was 65.6 feet per second while in the case of carbon monoxide the velocity was 7.9 feet per second. The results obtained by these two men, although they are very interesting, are somewhat difficult to apply in the present form to the gas engine.

The results obtained by Mr. Dugald Clerk are given in a practical form so that it is easy to them in determining the proper point of ignition in a gas engine without compression. The apparatus he used to obtain his results consisted of a cast iron cylinder seven inches in diameter and eight and one quarter inches long. This cylinder was filled with the explosive mixture which was ignited by means of an electric spark. The pressure in the cylinder was recorded by the pencil of an indicator on a paper fastened to a rotating drum that was driven by clock-work so as to make one revolution in .3 seconds. The distance between ignition and maximum pressure was then measured from the

card from which the time of combustion is easily computed. Dugald Clerk made many test with this apparatus and obtained some very valuable data on the time of combustion, yet the conditions under which the tests were made do not conform with those of the gas engine in operation. All the tests were made with the mixture at atmospheric pressure (14.7 pounds per square inch) before ignition. Mr. Dugald Clerk states that he found that a mixture of 1 to 11 was the most economical in a gas engine. From his determinations of flame propogation, we find that the time of combustion for this mixture was .18 seconds. Let us take these results and see if we can apply them to a gas engine in operation. Assume the speed to be 240 revolution per minute or 1440 degrees swept out by the crank in one second. If now we want the maximum pressure to occure at "dead center" the ignition of the charge, according to the above data, should be .18x 1440 or 259.2 degrees before "dead center". This, of course, is never found in practice and shows that the determinations can not be applied in their present form to a gas engine with compression. It would be possible to compress the explosive charge in a cylinder similar to that used by Mr. Dugald Clerk but even in that case the conditions would differ slightly from that found in the gas engine since in the latter the compression varies after the charge is ignited.

The experiments of the above mentioned men and many others that worked along this line have all been carried on with special apparatus. The advantage that they gained by this was the ease of observation and the elimination of all points that might prevent them from obtaining consistent results. The results obtained by these men lack the practical features of those obtained from a gas engine in operation. The best method to determine the time of flame propogation that will be applicable to the actual engine is to make the observations from the engine direct, then there can be no question of assuming ideal conditions that do not exist in the cylinder. The first thing we decided in connection with this test was to make all our observations relative to the time of combustion on the gas engine.

The next question that arose was, what method should be employed to obtain the time between the spark and maximum pressure? The apparatus employed by Mr. Dugald Clerk could be easily be applied. A second method although similar to Clerk's apparatus in principle yet differs somewhat in one feature could be made to give, we think, a fairly reliable record. This apparatus would consist of: indicator; tuning-fork with stylus or pencil; motor; two drums. A long strip of paper could be fastened to one of the drums, wrapped around the second so that when the motor rotated the first drum the paper would wind upon the same.

The tuning-fork could be so arranged ~~x~~ as to have the pencil fastened to the same directly over pencil of the indicator. The indicator would record the different pressures on the moving paper while the tuning-fork would trace a curve from which the time could be computed. The point of ignition and maximum pressure could be easily determined from the card taken and the time between the two calculated. This scheme has the advantage over that used by Mr. Dugald Clerk in flexibility of speed, also in the elimination of any error due to the friction of the pencil of the indicator. These two plans although they would undoubtedly give the results sought lack both in originality and scope. A method suggested by Prof. R. Burnham for taking photographs of the explosion not only promised to give accurate results but also a physical conception of what is taking place inside of the cylinder during combustion. The principle upon which this method works is very simple; a photographic plate is allowed to fall in front of an opening in the gas engine cylinder and a continuous picture is taken of the combustion. The plate first gets the impression of the spark; the combustion of the mixture then starts and the various stages of the same is recorded on the falling plate. The plate is then developed and the different portions of the plate are affected according to the light in the cylinder when that portion of the plate was exposed. It is a

well know fact that the luminosity of a burning mixture will be greatest when the temperature and the pressure is the greatest, so that we can say the time of combustion is that time that elapses between ignition and maximum temperature therefore maximum light. The holder for the plate was designed by Prof. R. Burnham.

The engine on which the observations were taken was a Fairbank Morse stationary gas engine. This engine was located in the Gas Engine Laboratory of the Armour Institute of Technology of Chicago. A short discription of this engine with the reasons and functions of the various parts is essential. The engine used was a horizontal stationary four-cycle engine size 6 3/4" x 12", rated 7 horse power at 240 R.P.M. A four cycle engine has only one explosion or impulse in two revolutions. The events in this type of engine are: first, explosion driving the piston forward; second, exhaust the piston expells the burnt gases on the backward stroke; third, the new charge is drawn in by suction when the piston again moves forward; fourth, compression of charge on return stroke. The method of igniting the charge is by what is known as the "make and break". In brief this consists of two terminals in contact inside the cylinder of the engine. One of the terminals is connected to a spring shown in the view of the cylinder head. The method of operation is as follows: A pin turns a sleeve, which is fastened to the spring, and then releases it. The spring has, in the meantime,

been in tension, holding the terminals together, on being released jerks back past its original position and separates the terminals. An electric current has, during this time, been passing through the terminals and as soon as they are brought apart, a spark leaps the gap and ignites the charge. There are two inlet valves on this engine, one being of suction type, the other being controlled by the same lever as the exhaust valve and is kept closed while the exhaust valve is opened. The reason for this can readily be seen when the type of governor is discribed. The governor consists of two weights held together by springs. The operation of the governor is as follows: The speed increases and the governor weights fly outward due to centrifugal force. The outward movement of the weights causes a sleeve to slide along the shaft. A long pin which is fastened to the sleeve is pushed in front of the exhaust valve stem preventing the closing of that valve. The exhaust valve being held open only the burnt gases are drawn into the cylinder on the next suction stroke so no work is done in the next two revolutions and therefore the engine slows up. From this it can be seen how necessary it is to have the inlet valve mechanically operated so that it may be held closed during the time the exhaust valve is open otherwise the fuel drawn in would be wasted. The water jacket was supplied from the city main and therefore no water pump was

necessary. The engine was fitted with a mixer and by turning the handle of the same we were able to vary the proportion of gas and air. The engine had two fly wheels, pulley, indicator cock, and reducing motion for taking cards.

Two gas meters were used in this test, one for illuminating gas, the other for natural gas. The same can be said regarding the pressure regulators, one being used for illuminating gas, the other for natural gas. When we ran the engine on natural gas we had to take this gas through the illuminating gas pressure regulator and, after the engine had been in operation some time, change over to the natural gas pressure regulator. The natural gas pressure regulator was made by the Westinghouse Co. and delivered the gas at atmospheric pressure. The illuminating gas pressure regulator was of the telescoping inverted water sealed tank type. A lever of a valve in the gas pipe was fastened to the top of the pressure regulator so that when the tank became filled with gas the upward movement of the inner tank would throttle the gas supply and ultimately shut off the gas. This gas regulator was used in starting the engine no matter what gas was used as it afforded a reservoir for a large quantity of gas under pressure so that the engine did not have to do any work on taking in gas on the suction stroke.

The water from the cooling jacket flowed into a large steel tank but as no account was kept of the water used during the test this piece of apparatus need not be described. After a number of ~~number of~~ preliminary runs had been made, an air meter was connected to the air side of the inlet mixing valve. The air meter was made by Harris Griffin Co. and is shown to the right in figure 2. On starting the engine it was necessary to uncouple the connection to the air meter as it was impossible for the engine to draw sufficient quantity of air through the meter for it to start upon. After the engine had been running for about two minutes we could connect the meter to the air inlet and had no trouble in drawing the air through the same. The natural gas meter was made by the Westinghouse Co. while the meter used for illuminating gas was manufactured by John J. Griffin Co.

The "plate drop" was the name we gave to the vertical plate holder which was fastened to the engine. The reason for this name was to distinguish it from the plate holders which we made for holding the plates before they were exposed. The "plate drop", shown in figures 7 and 8, was, as has been stated before, designed by Prof. R. Burnham. It consisted of long beass strips fitted together so as to leave a slot 1/16 by 1 1/8 inches for the plate. The entire apparatus was light proof having caps for each end.

[illegible] that was put into this "plate drop" [illegible] and was brought [illegible] pin [illegible] through [illegible]. This pin was fastened to a lever arm which was held in the present position by a light spiral spring. The lever arm was pivited as is shown in figure 7. A small piece of iron hinged at the side of the electro-magnet had an arm that extended to the lever. The electro-magnets consisted of two coils, one connection being made at a binding post, the other on the "plate drop". When a current was allowed to flow through the coil the magnetic attraction caused the iron strip to move toward the magnets. The movement of the iron strip caused the lever arm to move and this, of course, pulled the pin from under the plate and allowed the same to fall. A little over an inch below the pin was an opening in the "plate drop" which was circular and something over a half an inch in diameter. It was through this opening that the light that was to effect the plate had to pass. In front of the opening in the "plate drop" was a slide to prevent the light from entering the holder when the same was disconnected from the engine. The "plate drop" was fastened to the tube shown in figure 9. This tube was threaded and fitted in a tap made in the cylinder [illegible] of the engine while the other end of the tube was fastened to a plate in which the lense was mounted. The lense was held firm by a metal ring which pressed it against its seat on [illegible]

The tube was [illegible] for mounting the plate [illegible] and by a support to which the "plate drop" could be fastened by means of two screws. The "plate drop" as originally designed was supposed to be loaded in the dark room. The slide was then closed and the two caps were placed in position. The "plate drop" was then fastened to the tube, mentioned before, after which the slide was opened. We tried this method one day but concluded that too much time was wasted in loading plates and therefore decided to make plate holders. The plate-holders had to be as simple as possible, of large capacity, and reliable. It was some time, nevertheless, before we decided upon the design from which we at last made the plate-holders. The plate-holders were in principle as follows: Boxes with slots for the plates, a light tight compartment on top of the "plate drop" also one at the bottom. We made three plate-holders two with thirteen slots and one with eleven. The plate-holders were made of wood nailed and glued so as to make them very strong and were also given a number of coats of black shellac so as to insure ~~them~~ their being light tight. These plate-holders were made eleven inches long as we intended at first to use plates one by ten inches. A small cushion was placed at the bottom of each [illegible] so that the plates would not break if the box was handled roughly. The [illegible] shown in figure 5 with the plate holders, [illegible]

made of cardboard covered with paper, glued and shellaced throughout. The frame-work for the upper light tight compartment is shown in figures 4 and 5. The plate-holder in position is shown in figure 5. The cap, it will be noticed, is removed so that the plates in the inverted plate-holder rest upon the table of the frame-work. The plate-holder can be pushed along between the two wooden guides that determine the travel of the holder. In figure 4, which is the top view of the upper frame-work, we can see a slot which leads directly to the plate slot in the "plate drop", and one can easily see that when the plate-holder is pushed over this slot ~~that~~ the plates will fall out of the holder and through the slot. The person in charge of the plate dropping could easily tell when a plate had fallen from the holder into the "plate-drop" by feeling the slight jar that was caused when the plate struck the pin. The lower light tight compartment was made so as to support a plate holder, the original plan being to place an empty holder as is shown in figure 6 to catch the plates as they came through the "plate drop". When we started making the runs we found it necessary to mark the plates so one man had to have his hand in the compartment, so it was easier to place the plates into a card-board box after they had been labled. The photos taken show the frame work

[illegible] they are shown as they were used in the test. The covering consisted of three thicknesses of black cloth. The upper compartment had two openings, one through which to put the plate-holder, the second through which a person could get their hand so as to remove the cover from the holder. The bottom stand had only one opening and a person could get one hand in so as to catch the falling plates, mark them, and place them in card-board boxes. This scheme of plate-holders worked very well and caused but very little trouble.

The entire success or failure in timing the falling plate so as to have the same in front of the opening in the "plate drop" during combustion depends upon the contact device. The contact, shown in figure 1, was on the engine before we started the test so we thought it best to give it a trial. The igniter arm A moved right and left with an oscillating motion. The plate F was insulated from the engine. The threaded portion G passed through a tap in C. B slipped over the plain surface of G when pressed upon by E. A spring in B kept this part in its extreme position. There was also a slot in B through which a pin fastened to G extended thus preventing B from falling off. The binding post D was connected by a copper wire to the binding post of the storage battery. Three double cell storage batteries were used in series giving about 12 volts. The other terminal of the series of batteries was

was connected to the binding post of the "plate drop". From the discription of the contact device it can be readily seen that when the nut E comes into contact with ~~with~~ B ~~that~~ the circuit would be closed which would cause the catch to pull out the pin and allow the plate to fall. The threaded portion on G was to allow a greater range of adjustments for timing the plate. In the discription of the different runs it will be found that this adjustment did not give consistent results so a new contact had to be devised.

The contact on the cam was the successful one and after we had it perfected it never gave us any trouble. The plan of contact was this: A portion of the cam was insulated and a strip of brass held by a block of wood pressed against the face of the cam. A copper wire was fastened to the strip of brass and was connected to one terminal of the series of batteries whose other terminal was connected to the binding post of the "plate drop". The circuit was open as long as the strip of brass pressed upon the insulation but as soon as the brass came into contact with the surface of the cam the circuit was closed and the catch would allow the plate to fall. We first tried to glue a piece of paper on the cam and have this for the insulation but the paper would not stay on after the glue got dry. Our second attempt of fasten-

ing insulation material to the cam was more successful. We cut a piece of mica in the shape of the face of the cam, then cut a portion of the mica away so that the brass strip would be in contact for 180 degrees of crank movement. By calculations we determined that the plate should fall 18.5 degrees of crank position before the crank position for ignition. We fastened on the mica so that the contact of the cam and brass strip was made about 20 degrees before crank position for the spark. The mica was held to the cam by a coat of shellac. A brass spring was also fastened to the wooden block that was for the purpose of pressing the brass strip against the cam. The first run we made with this contact we noticed that the brass strip was tearing a groove through the mica and so as to prevent this in the future we fastened, by means of shellac, a piece of paper over the mica. The paper, we found, was better able to resist the tear and wear of the constant rubbing of the brass strip than the mica.

Preliminary to the actual runs, a number of plates of different brands were run through: (1.) Hammer; (2.) Seed's Gilt Edge; (3.) Cramer-Isochromatic. The developer used was Eiko-Hydro Developer. Upon development of these plates it was found that due to the lateness of the plate in falling, no trace of the spark or explosion was found, except in one case where due to inaccuracy in cutting, the plate stuck and the explosion

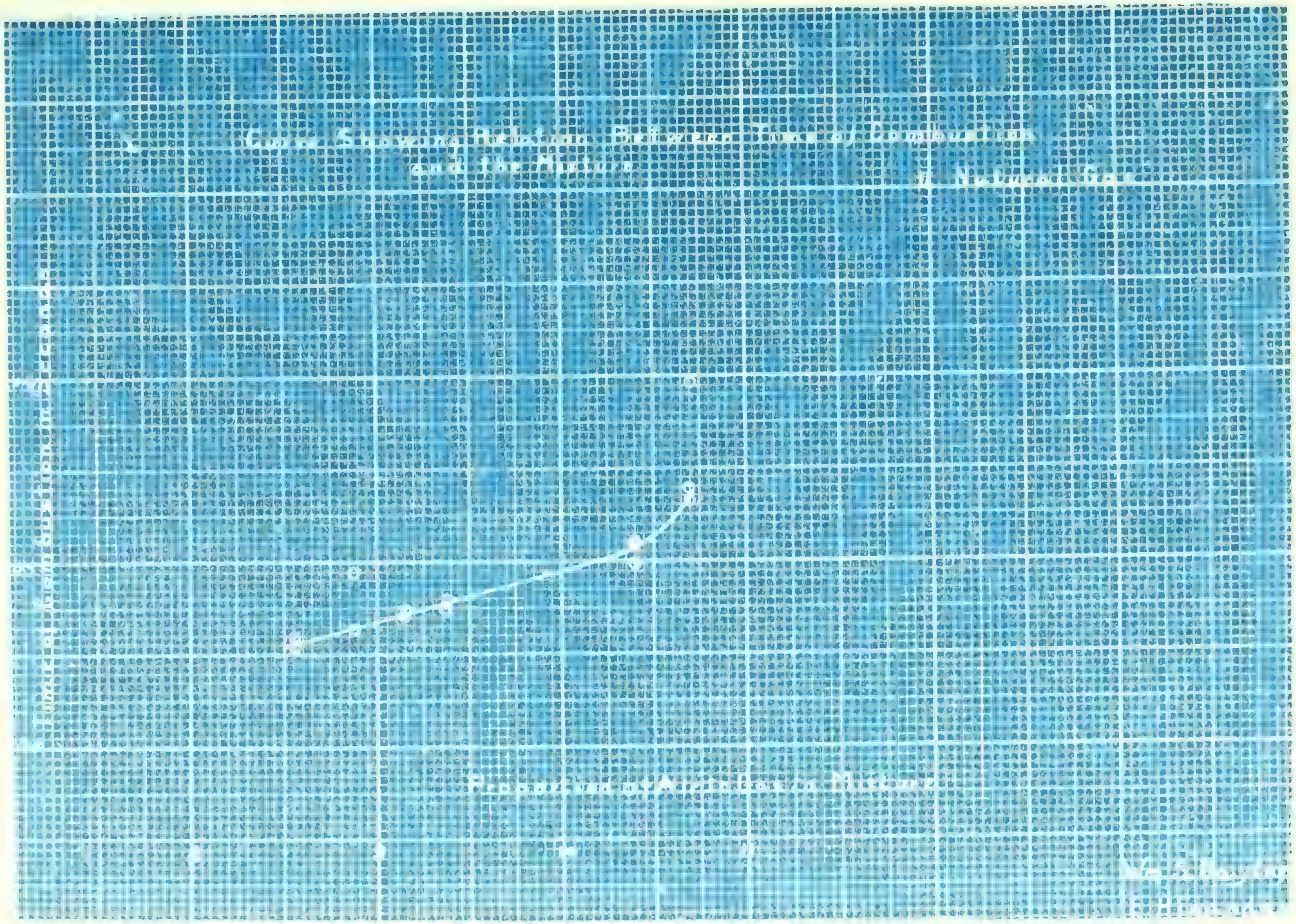
showed as a round spot. No conclusions could be drawn from this regarding the superiority of one plate over the others.

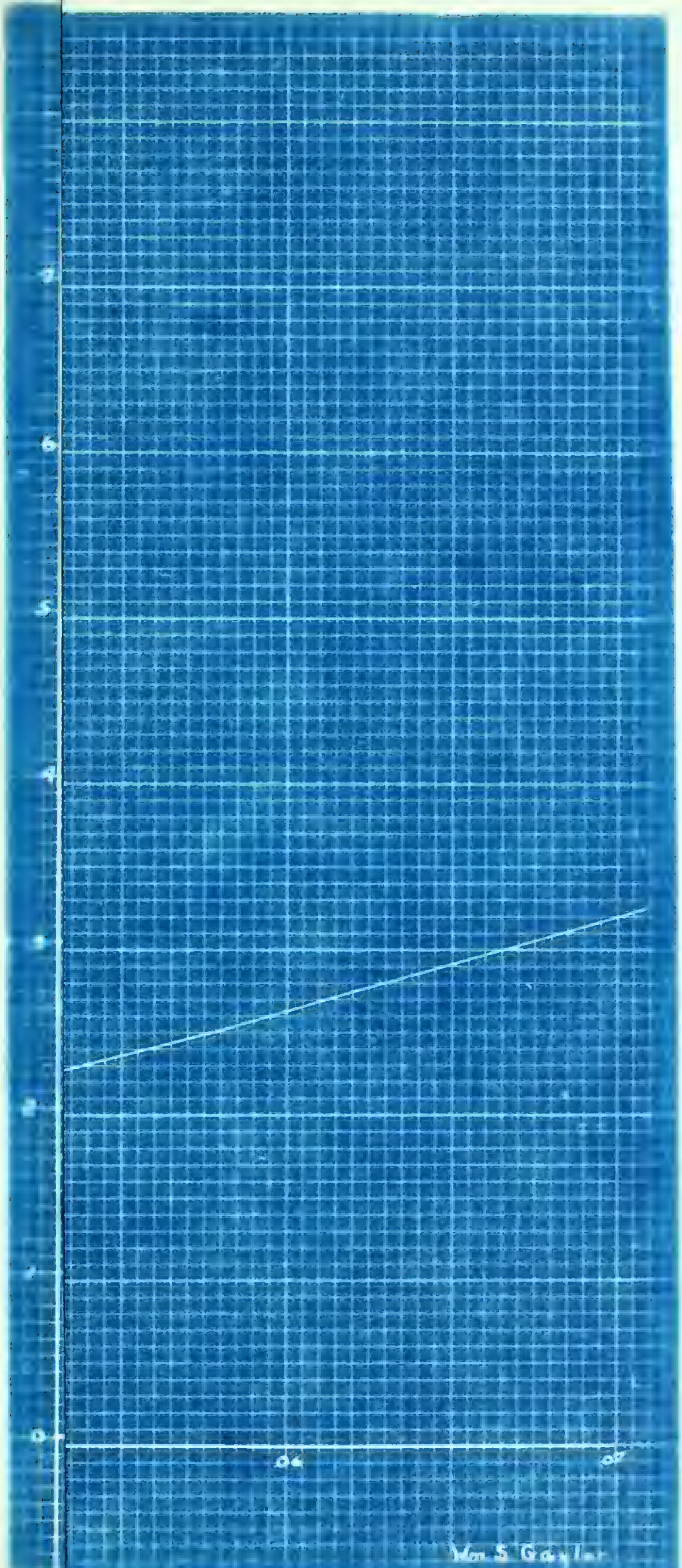
On the advise of Mr. J. H. Mulvey, Cramer Crown Plates – size 8"x10" were procured. The developer he recommended was a concentrated solution; the formula being:

1 part	saturated	solution	Sodium	Carbonate
1 "	"	"	Potassium	"
2 "	"	"	Sodium	Sulphite.

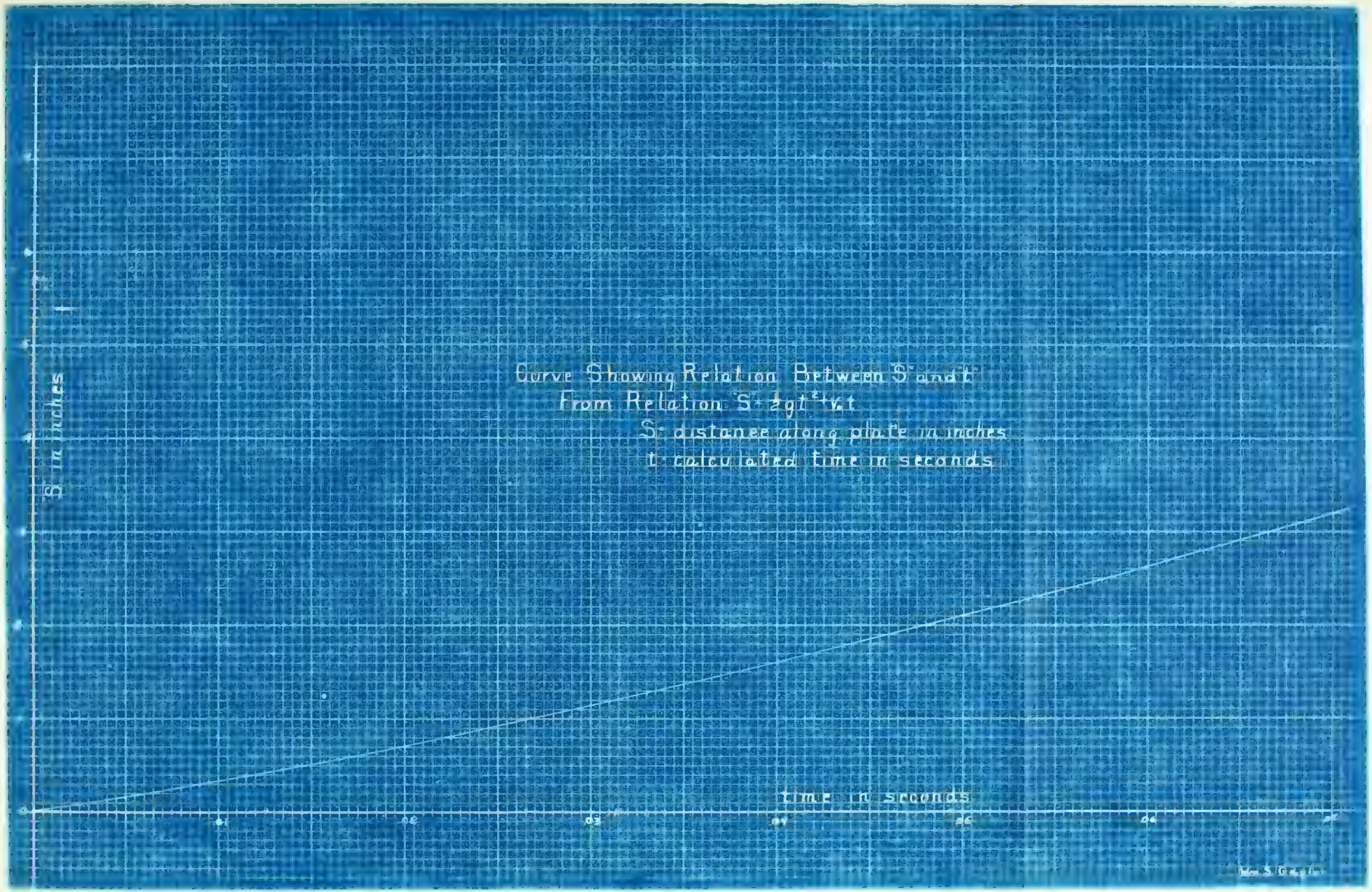
All the Hydrochinon that the solution would dissolve.

The Cramer plates were cut into the required size and a number of runs made with these plates. No trace of the spark or explosion could be found except in one case, a slight impression of the explosion. The conclusions drawn from this part of the work were two: (1) that owing to the faulty contact design for dropping the plates, the plates dropped some time after the explosion. (2) that the plates used were not sensitive enough to yellow light to be affected. This necessitated a change both in the contact and in the brand of plates used. The plates most sensitive to yellow light are Seed's "C" Ortho Chromatic, and this plate was used in the remainder of the work. The formula for the developer recommended by the Seed's Co. for these plates is as follows:


Curve Showing Relation Between Time of Combustion
and the Ratio



Wm S Gaylor



Curve Showing Relation Between S and t
From Relation S = ½gt² + v₀t
S = distance along plate in inches
t = calculated time in seconds
S in inches
time in seconds

"A" [illegible] [illegible]

[illegible] [illegible] oz.

[illegible] [illegible]

[illegible] [illegible]

"B" Pure water [illegible]

C.P. Carbonate Soda [illegible]

Use { "A" - 2 oz. "B" - 1 oz.

The question of a suitable contact was next to be considered. After a consideration of many possible devises, the following one was chosen, which proved very successful: The exhaust valve cam was partly covered with a sheet of mica fastened to the same by a coat of shellac. A strip of brass [illegible] at the cam and was insulated from the engine by being fastened to a block of wood wedged in between the oil cup of the cam-shaft and the main bearing. As mentioned before a wire from this brass strip led to one terminal of the batteries. [illegible] calculations the plates should fall 18.5 degrees after [illegible] so that the lowest portion of the plate would be opposite the [illegible] when ignition took place. We adjusted the contact so that the circuit was closed [illegible] ignition. Sample plates were run through and developed, [illegible] apparatus. The reason for this was not [illegible]

[illegible] last [illegible] took some perceptible amount of time for the [illegible] up a field [illegible] the catch to be removed from below the plate. Reasoning from this bases, it was evident that the plate dropped too late, and the remedy for this was to make the [illegible]. [illegible] methods of doing this suggested [illegible] by shortening the [illegible] by removing a portion of [illegible]. The latter method was chosen on account of the ease and accuracy with which these alterations could be made. A portion of the [illegible] was cut off and some more plates were dropped. These plates gave the results shown in figures (II) plate (13) which show the latter part of the [illegible]. This method of cutting off the insulation and dropping the [illegible] was continued until the [illegible] shown in figure (III) plate 13 [illegible] rotated 260 degrees before [illegible] broken 140 [illegible] and "dead center".

The mechanical difficulties being overcome it was necessary [illegible] to obtain an impression of both the spark and explosion. The latter had shown up so well [illegible] was no question of us getting a picture of the explosion. The [illegible], did not

[illegible] of the plate [illegible] was thought [illegible] necessary to make a special test to determine the possibility of obtaining [illegible] [illegible] of the spark [illegible] [illegible] [illegible] snap the [illegible] the engine not running. The results obtained is shown [illegible] (1) plate (13), where the plate was supported by a [illegible] paper before the lense, 12 [illegible] being used for the spark. This proved conclusively that it was possible to obtain a picture of both the explosion and the spark. A few [illegible] [illegible] [illegible] both the spark and explo[illegible] [illegible].

Now that it had been shown that picture of spark and [illegible] could be obtained, the actual work of determining the [illegible] [illegible] [illegible] and Illuminating Gas [illegible] engine would [illegible] determine for each [illegible] the time of combustion [illegible] the [illegible] pressures. We made [illegible] [illegible] the [illegible] [illegible] have any significance [illegible] necessary to [illegible] some of the conditions under which the engine [illegible] [illegible] time. The observations made for each [illegible]

(1) [illegible] pressure [illegible]

(2) Temperature [illegible] gas;

(3) pressure of atmosphere [illegible] gas [illegible]

(4) R.P.M. of [illegible]

(5) Explosions [illegible]

In addition to this indicator diagrams were taken, and a number of [illegible] dropped. It was necessary to repeat some of the runs where the spark and explosion were not clearly [illegible]. It was necessary to take the temperature and pressure of the air and gas [illegible] to standard [illegible] of [illegible] degrees F. The reduction was made by the thermodynamic equation $p'v'/T' = p''v''/T''$ where p' is the pressure of the gas in inches of mercury, v' is the volume in cubic feet, T' [illegible] the absolute temperature [illegible] the [illegible] [illegible] [illegible] [illegible] conditions. The readings [illegible] [illegible] [illegible] The [illegible] then dropped in the manner previously [illegible]. The temperature and pressure of air and gas [illegible] indicator diagrams taken, R.P.M. counted, Ex.P.M. counted. [illegible] [illegible]

The plates were developed [illegible] after [illegible] and [illegible]. The developer recommended [illegible] as it required a considerable length of time for the development of each plate, [illegible] greatest possible [illegible] The impression of the spark could [illegible] the plate [illegible] being developed, but after the negative [illegible] the fixing, when the spark showed up [illegible] the spark was [illegible] of the [illegible] from the [illegible] In almost all cases we found it necessary to [illegible] This [illegible] was done with a solution of potassium [illegible] It was necessary [illegible] several [illegible] for the varying [illegible] negatives were made upon Velox as this [illegible] would bring out the highest [illegible] plates # 1 — #6 inclusive are prints of runs #1—#6 [illegible] Gas. Plates #7 — #12 show prints of [illegible] Illuminating Gas. It has been suggested by Prof. B[illegible] [illegible] difficulty in printing as it was necessary [illegible]

[illegible] possible, to make a [illegible] the minor tones of the negative. If [illegible] was overexposed the difficulty could be [illegible] slower plates.

In order to facilitate the computation of the time of combustion it was thought advisable to make a series of calculations [illegible] plotted so that the time of combustion could be measured directly from the plates. The formula used for these calculations was the law of falling bodies:

$$S = \frac{1}{2}gt^2 + Vt$$

where:

S = the space passed over in inches on plate

g = gravity in inches per second per second = 385.92

t = time of falling in seconds

V = initial velocity in inches per second, due to the plate falling through the height of 1 11/32 inches, which is the distance from the center of the lens to the top edge of the plate. [illegible] required for the plate to reach the middle of the opening [illegible] seconds.

The table shown on the following page gives the results of calculations from the above formula for every [illegible]

Calculations from the formula S = [illegible]

S is the length of plate expressed in inches

g [illegible] in inches per second per second

t [illegible] in seconds

v [illegible] velocity in inches per second

S	t	S	[illegible]
[illegible]	.00744	[illegible]	[illegible]
[illegible]	.01431	4.00	.08295
[illegible]	[illegible]	4.25	.08675
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.75	.09425
[illegible]	.05795	5.00	[illegible]
[illegible]	[illegible]	[illegible]	.10155
[illegible]	[illegible]	[illegible]	.10485
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
3.00	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible] plate. The accompanying curve shows the graphical [illegible] "t".

In measuring the time of combustion from the plates the bottom of the plate was set upon the horizontal axis of the curve in such a place that the center of the spark intersected the curve. The time corresponding to this intersection was noted. The plate was then [illegible] point of the curve that it cut the highest part of the [illegible] noted. The [illegible] between the spark and maximum pressure. These results were checked by measuring the plates in the following manner: The distance between the spark and the highest portion of the explosion was measured to .01 of an inch. The distance from the spark to the bottom of the plate was measured from the negative as the bottom of the plate was not clearly defined on the print. These [illegible] were then added together and the corresponding time taken from the curve. The time from the bottom of the plate to the spark was subtracted from this value to give the time of combustion. These results checked very closely. Due to the fact that the crank swept out and angle of about .0048 degrees in .0001 [illegible] we did not carry the calculation further than the third

[illegible] pressure.

[illegible] results are shown in the following table. [illegible] curves were plotted [illegible] for Natural Gas [illegible] for Illuminating Gas, shown in the following [illegible].

The time of combustion for the Natural Gas varied from .038 [illegible] a mixture of 10.7 [illegible] to .025 for a mixture of 8.55 [illegible] [illegible] with the [illegible] [illegible] time of combustion [illegible] [illegible] position taken. The reason why we did not obtain a wider range of mixtures was [illegible] Dugald Clerk in his famous experiments [illegible] .09 seconds. The [illegible] this case was due to the fact [illegible] experiments were carried on at atmospheric pressure.

For Illuminating Gas the time of combustion varied [illegible] [illegible] [illegible] [illegible] mixtures the time of combustion differs by [illegible] seconds [illegible].

[illegible] on the combustion of gases [illegible] different [illegible] say how

[illegible]

[illegible] very far from [illegible]

[illegible] combustion [illegible]

[illegible] The results obtained by Dr. [illegible] have been

[illegible] have been set forth.

In making the calculations we did [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] The shape of the curves [illegible]

[illegible] the rate of combustion [illegible]

[illegible] is true for this initial pressure [illegible]

[illegible] It will be noticed, however, that

[illegible] in the rate of combustion [illegible]

[illegible] experiments [illegible] carried on at [illegible]

curve [illegible] the illuminating gas would indicate that these

[illegible]

[illegible] increased very rapidly and then [illegible]

[illegible] combustion decreased very fast. [illegible]

[illegible]

give a conception of what is actually taking place in [illegible]

[illegible]

[illegible]

to effect the piece but gradually the flame spreads through the mixture and the light from the same increases until the maximum brightness is obtained when the entire mass is on fire. The luminosity does not vanish directly after the combustion of the gas but continues for about .03 to .04 seconds. In conclusion it may be said that this method not only afforded an accurate means of determining the time of combustion but also gave a physical conception of an explosion in a gas engine cylinder.

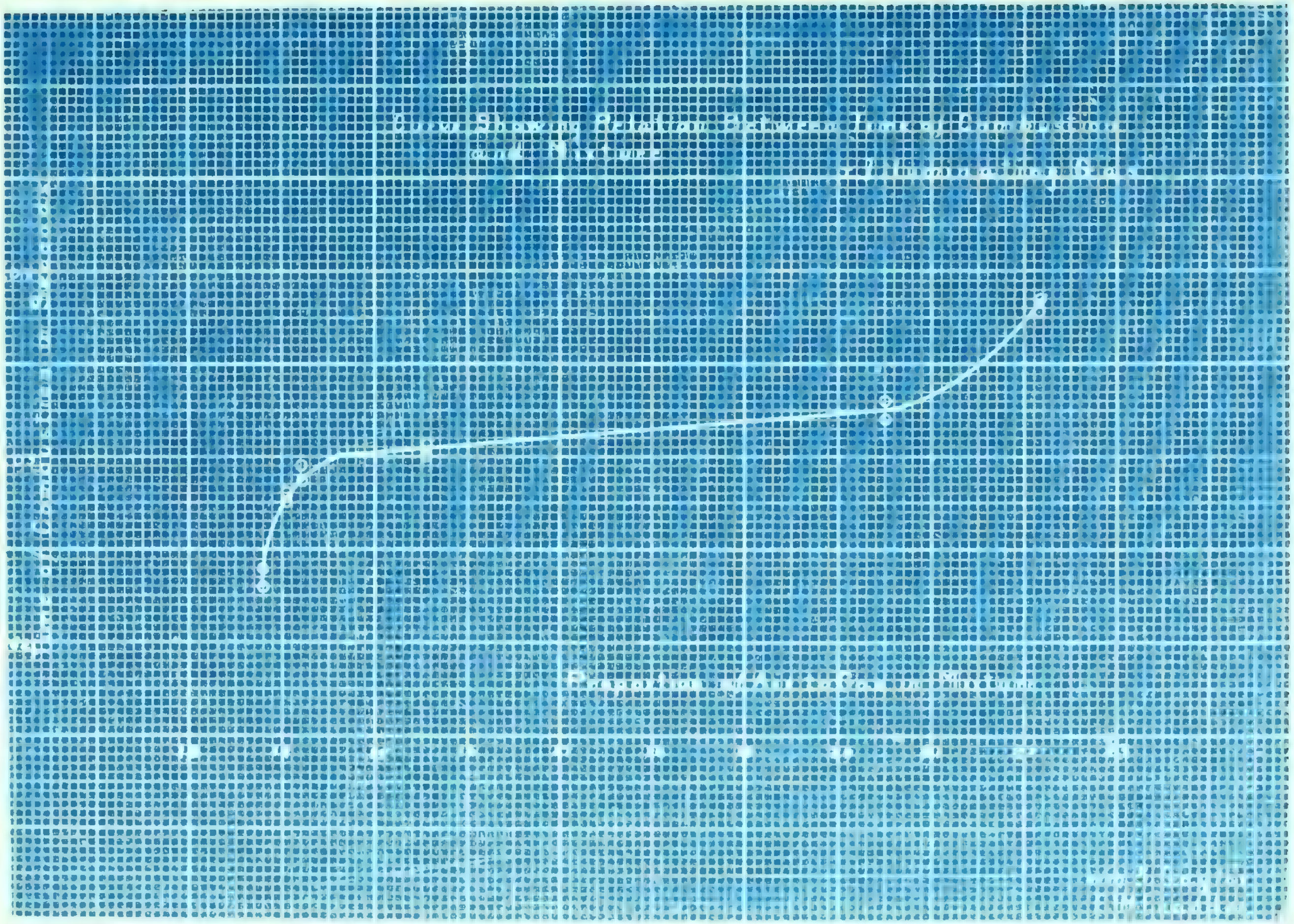
Wm. S. Taylor.

Einar A. Enander.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air in cubic feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gas in cubic feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Temperature air F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Temperature gas F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pressure at gas meter in inches [illegible] above [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Air cu.ft. at 32° F and 30" Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gas cu.ft. at 32° F and 30" Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Proportion air to gas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Barometer inches Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Time of combustion calculated for [illegible] expressed in seconds	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]			[illegible]
[illegible] P.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]x. P.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Illuminating Gas [illegible]

Run.	1	2	[illegible]	[illegible]	[illegible]	[illegible]
ir in cubic feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
as in cubic feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
emperature of air F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
emperature of Gas F.	[illegible]	[illegible]	75	[illegible]	[illegible]	[illegible]
ressure at gas meter in inches						
g. above atmospheric pressure	[illegible]	.25	[illegible]	[illegible]	[illegible]	[illegible]
ir cu.ft. at 32° & 30" Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
as cu.ft. at 32° & 30" Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
roportion of air to gas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
arometer inches Hg.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ime of combustion expressed in						
econds calculated from places	[illegible]	[illegible]	[illegible]	[illegible]	.050	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]			.050	[illegible]
		[illegible]				[illegible]
R.P.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ex. P.M.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]


Curve Showing Relation Between Time of Combustion
and Mixture
of Illuminating Gas
Proportion of Air to Gas in Mixture

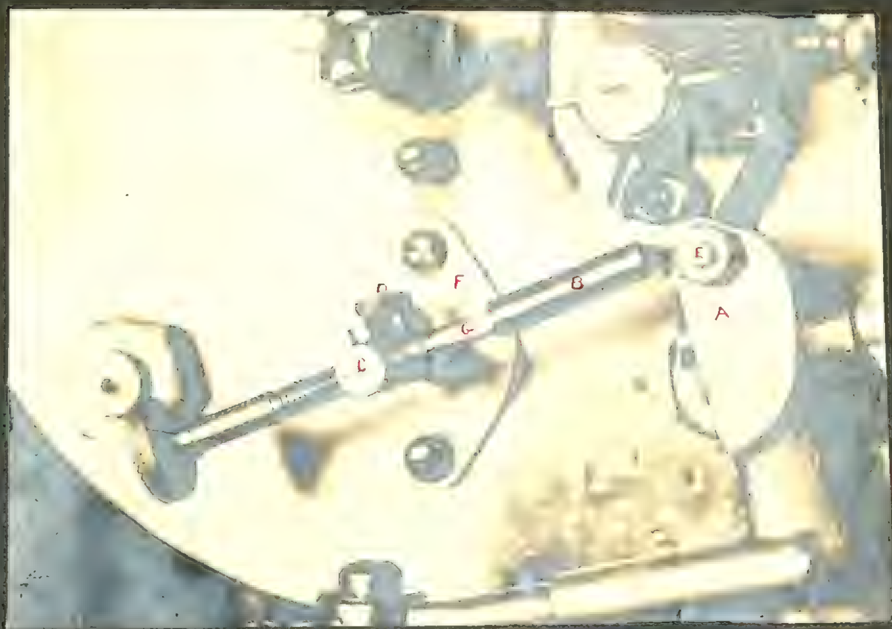


Fig. I.

Fig. 2.

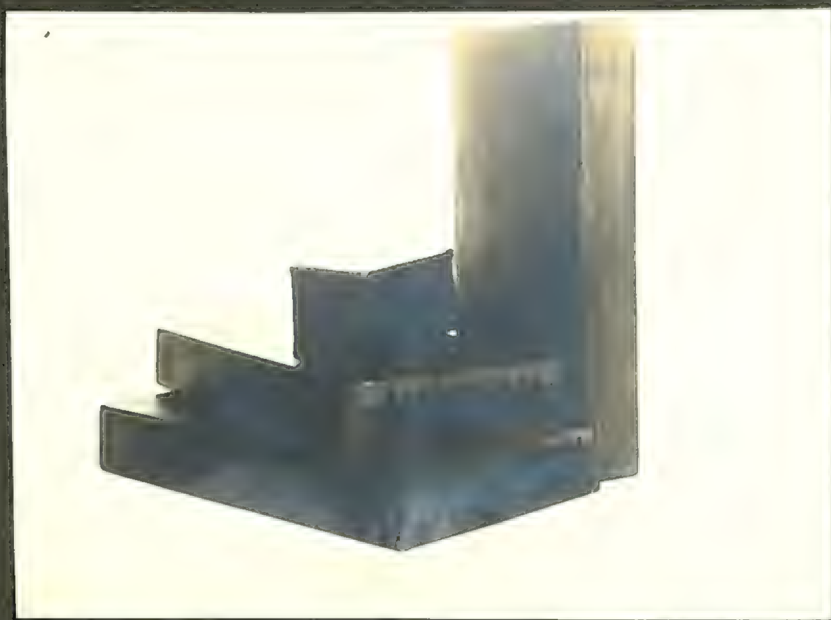


Fig. 3.

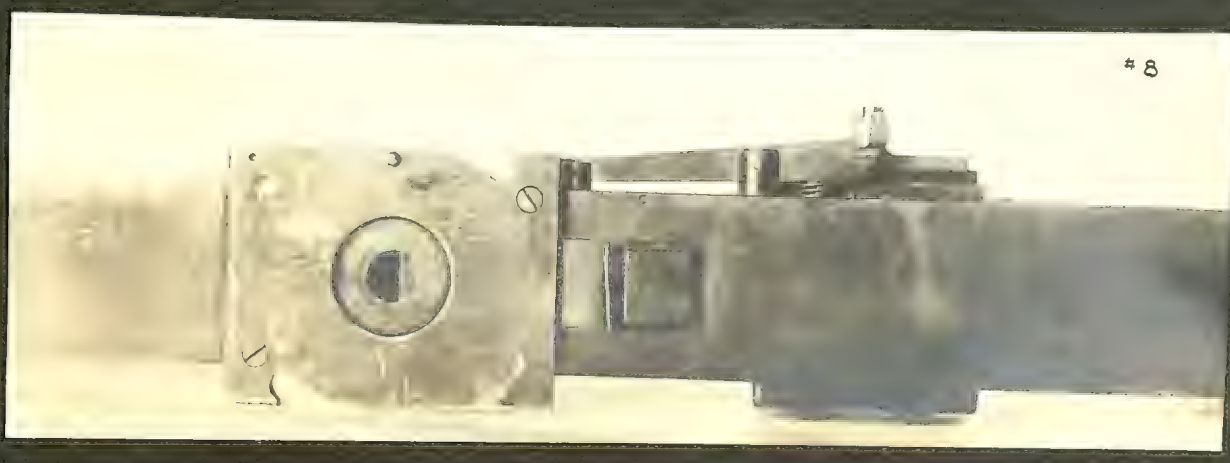
Fig. 6.

Fig 4.

Fig. 5.

#7

#9

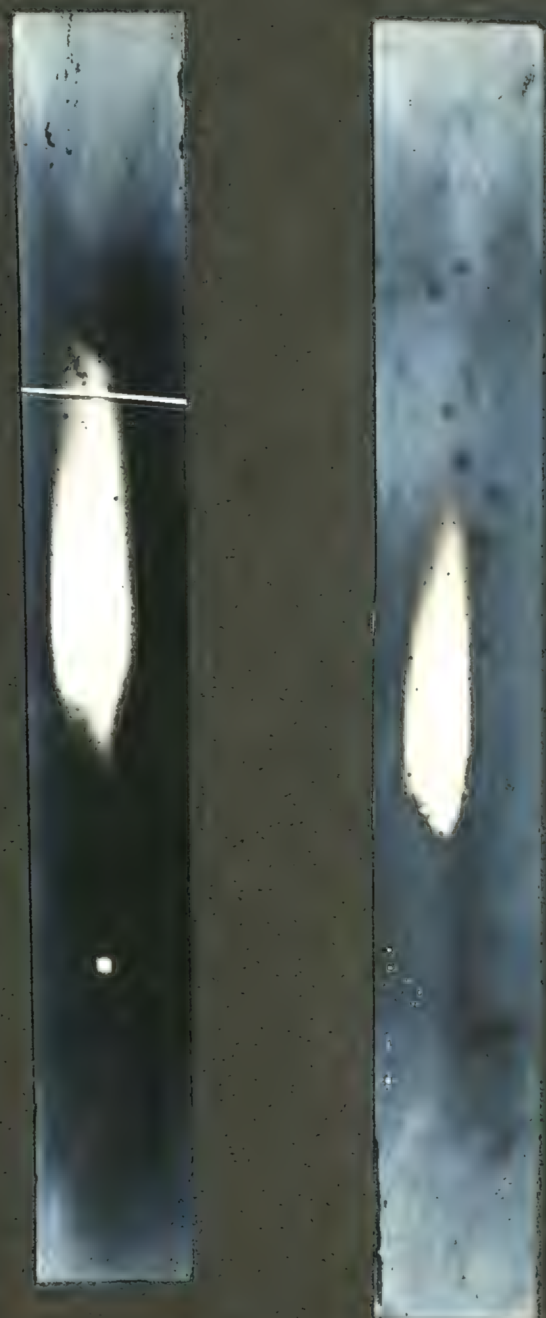


#8

#2

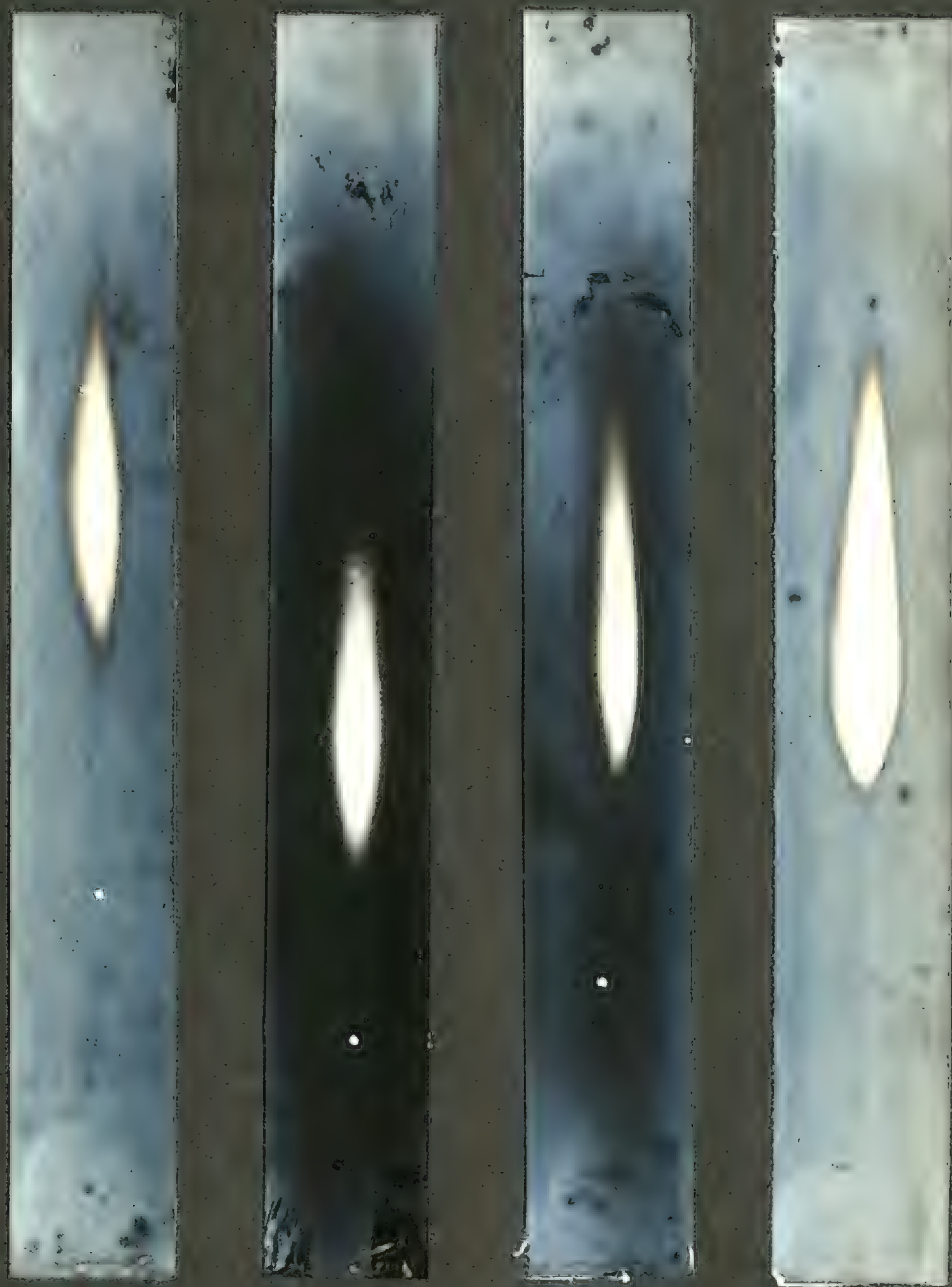
П 3

4.

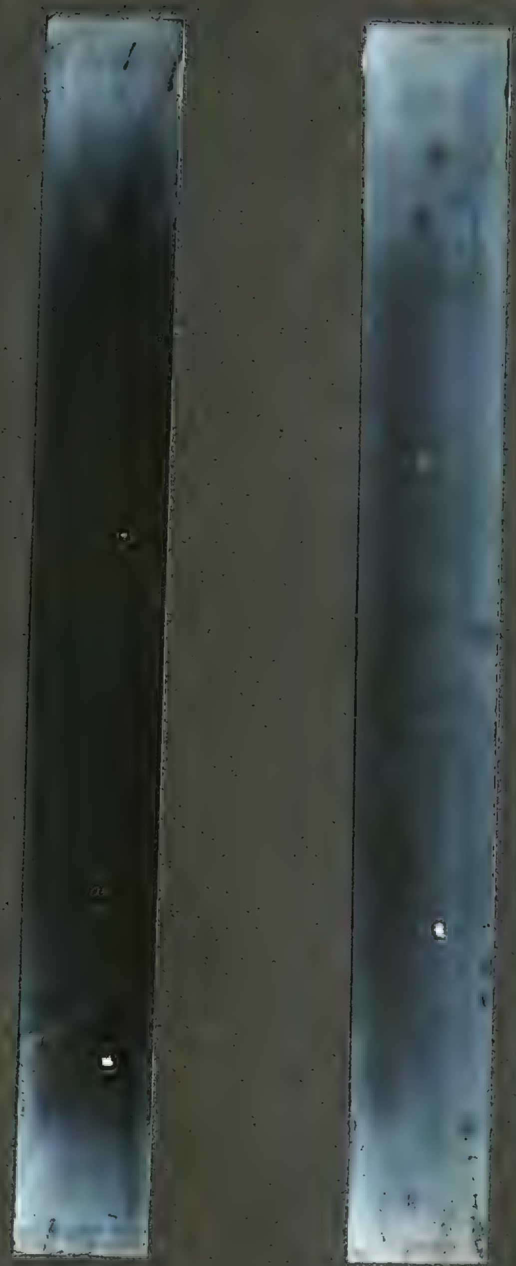


#5.

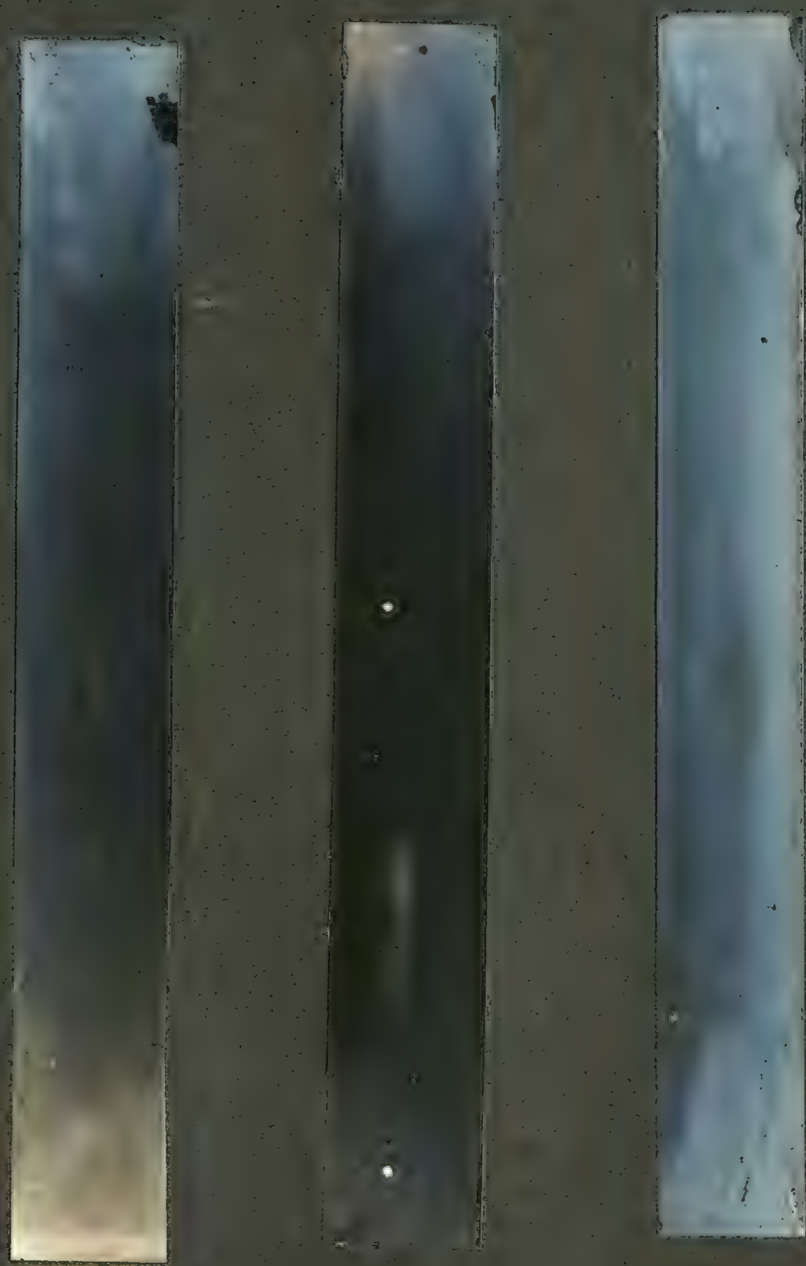
#6



7

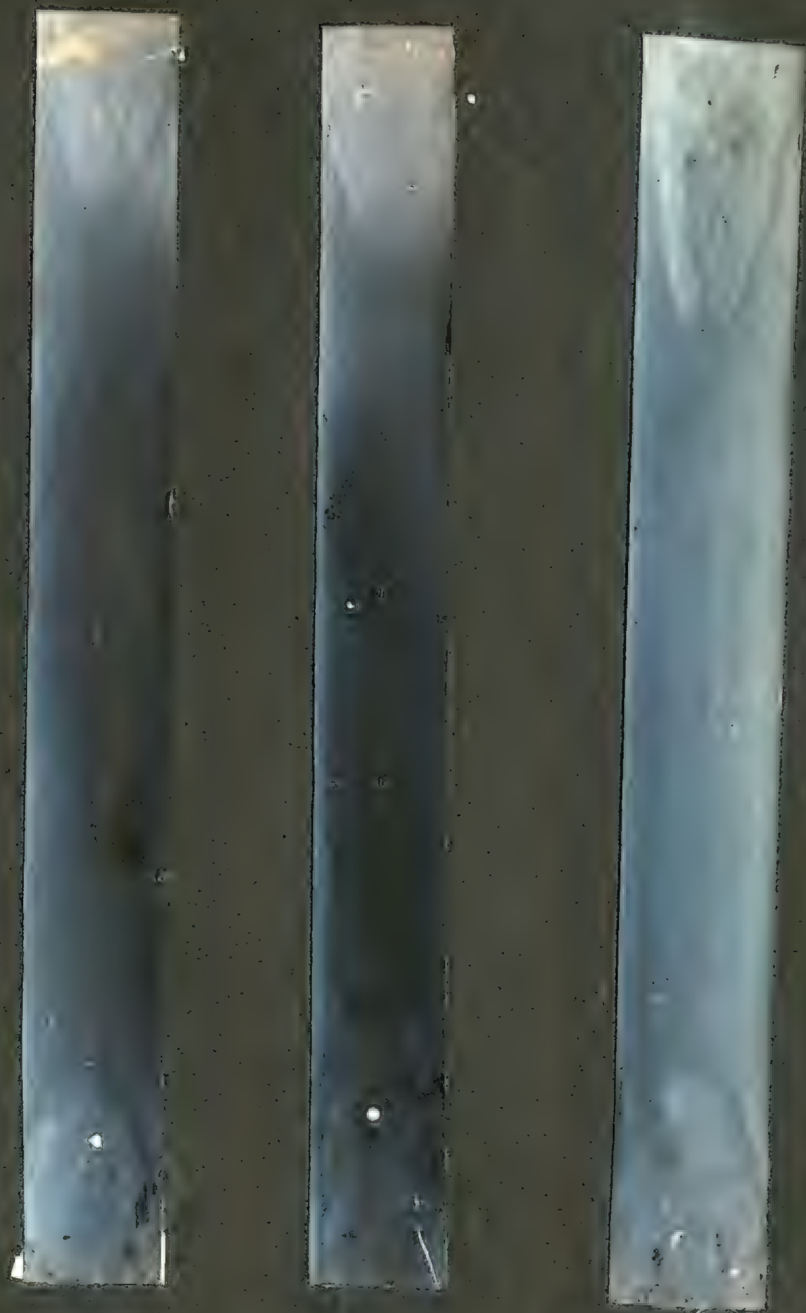


#8

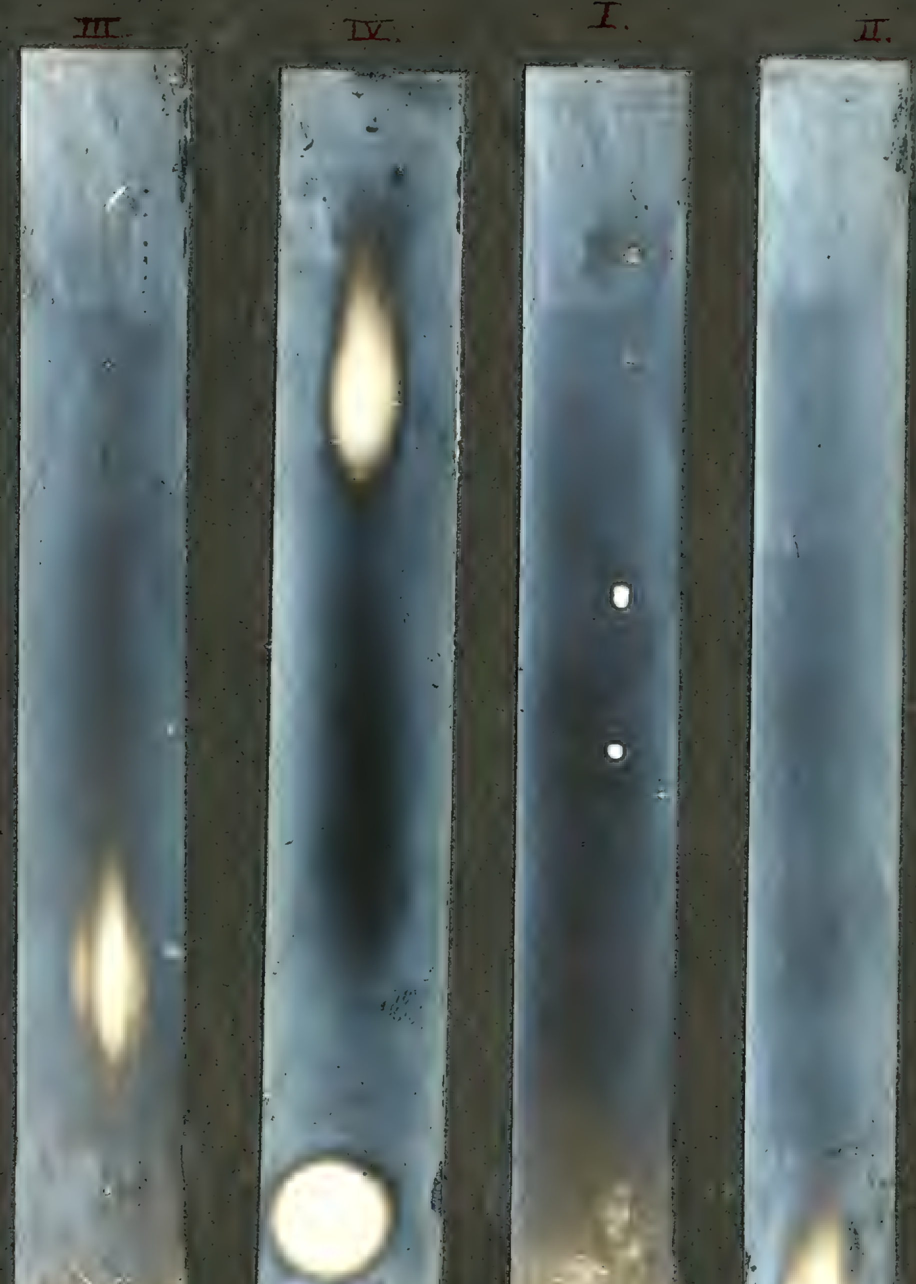


#10

#11



#12



#13